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Significance of the use of non-renewable fossil CED as proxy indicator for screening LCA in the beverage packaging sector

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Abstract
Purpose This study discusses the significance of the use of non-renewable fossil cumulative energy demand (CED) as proxy indicator in the beverage packaging sector, in order to detect those situations in which companies can benefit from the use of proxy indicators before a full life cycle assessment (LCA) application. Starting from a case study of two milk containers, the objectives of this paper are to assess if the use of this inventory indicator can be a suitable proxy indicator both (1) to decide which is the packaging alternative with the lowest environmental impact and (2) to identify the most impacting process units of the two products under study.
Method The analysis was made according to ISO14040-44. The goal of the comparative LCA was to evaluate and to compare the potential environmental impacts from cradle to grave of a laminated carton container and a HDPE bottle. The results of the comparative LCA obtained with the non-renewable CED indicator are compared with a selection of impact categories: climate change, particulate matter formation, terrestrial acidification, fossil depletion, photochemical oxidant formation. A further analysis is made for the two products under study in order to determine which are the environmental hot spots in terms of life cycle stages, by the means of a contribution analysis.
Results and discussion From the comparative LCA, the use of non-renewable CED revealed to be useful for a screening as the results given by the non-renewable CED indicator are confirmed by all the impact categories considered, even if underestimated. If the aim of the LCA study was to define which is the packaging solution with a lower environmental impact, the choice of this inventory indicator could have led to the same decision as if a comprehensive LCIA method was used. The contribution analysis, focusing on the identification of environmental hot spots in the packaging value chain, revealed that the choice of an inventory indicator as non-renewable CED can lead to misleading results, if compared with another impact category, such as climate change.
Conclusions As in the future development of beverage packaging system, LCA will be necessarily integrated in the design process, it is important to define other ways of simplifying its application and spread its use among companies. The LCI indicator non-renewable fossil CED can effectively be used in order to obtain a preliminary estimation of the life cycle environmental impacts of two or more competing products in the beverage packaging sector.

Keywords Beverage packaging · Cumulative energy demand · Life cycle impact assessment · Proxy indicators · Screening LCA

1 Introduction

The choice of the Life cycle impact assessment (LCIA) methods is important in an LCA, particularly with reference to the use of the results obtained from the application of LCA to a particular product or process. Depending on whether an evaluation of a specific impact category is required (Pant et al. 2004) or whether performance of a product or process from several viewpoints is needed (Mizsey et al. 2009), the assessment of the results from different LCIA methods could be critical for decision making. In fact, depending on the motivations and objectives, a particular impact assessment method

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or category may be more suitable (Dreyer et al. 2003; Bovea and Gallardo 2006).

It is known that differences between impact assessment methods are huge (Hauschild et al. 2008) and the effect of the impact assessment method on the final outcome of an LCA has previously been evaluated in many industrial sectors: plastic materials (Bovea and Gallardo 2006), chemicals (Dreyer et al. 2003; Pant et al. 2004) and PV technologies (Manzardo et al. 2011). A comparison of results obtained by applying different LCIA methods to the same product has not yet been presented in the packaging literature, particularly in the beverage packaging sector.

There are two recent bodies of work that relates to the selection of relevant LCIA categories for packaging (GreenBlue 2009; Consumer Goods Forum 2011). The first study aims to provide a comprehensive set of indicators and metrics focused on packaging-level measurement in order to define which attributes and impacts of packaging should be measured in terms of sustainability performance and why. With regard to the environmental aspect particular emphasis is given to the measurement of energy use, as there is a strict connection between this aspect and other environmental impacts. The burning of fossil fuel, indeed, releases many emissions, such as GHG emissions which contribute to climate change, sulphur dioxide which contributes to the creation of acid rain and particulate matter, which can influence human health (GreenBlue 2009). The study by Consumer Goods Forum (2011) distinguishes two types of life cycle indicators in the environmental area: inventory indicators and impact categories indicators. There are some indicators which are advised if energy from fossil fuels is used, such as global warming potential, particulate respiratory effects, acidification potential, non-renewable resources depletion. This is because the extraction and use of resources for energy generation is acknowledged as a major contributor to a wide range of environmental impact categories. For this reason, the inventory indicator fossil CED (Cumulative Energy Demand) (Frischknecht and Jungbluth 2007) has historically been used as a proxy indicator for other environmental impact categories in LCA screening studies and its appropriateness as an indicator for the environmental performance has been tested for the following product categories: energy production, material production, transport and waste treatment (Huijbreghts et al. 2006).

Furthermore, the calculation of the direct and indirect use of energy associated with the life cycle of products has been widely discussed in the development of the LCA methodology. The very first studies of life cycle energy analysis refer to the calculation of the cumulative energy associated with the production of beverage containers (Hannon 1972), and the importance of net energy analysis for technologies assessment (Brendt 1982; Hannon 1980). In the paper of Hannon (Hannon 2010), the objective of life cycle energy analysis was to compare the system of refillable containers and the system of throwaway containers (Hannon 2010). The interest on energy savings has been always relevant in the packaging sector. In fact, the first LCA applications were focused on the energy aspects relevant to different types of beverage containers (e.g. plastic, glass and aluminium) (Hunt and William 1996).

Within the packaging sector, the beverage packaging industry play an important role in the protection from environmental influences, such as heat, light, moisture, oxygen, pressure, enzymes, microorganisms, dust particles, which can cause deterioration of the beverages, but it can generate potential adverse impacts to the environment over its life cycle. In recent years, many companies in the beverage packaging sector (Von Falkenstein et al. 2009) have been utilising LCA as a tool to analyse the environmental performance of their packaging systems and the number of potential applicants is increasing.

As LCA can be used both for product improvement (internal use) and product comparison (external use), different situations need to be discussed within this sector. For instance, when the aim of a company is to compare the environmental performances of its products with competing products for comparative assertions intended to be disclosed to the public, the same data quality for both products has to be provided, according to the ISO 14040-44 standards. Data collection is a time- and resource-demanding task, which requires a close cooperation between the companies involved in the study.

Another typical situation refers to the identification of opportunities to improve the environmental performance of products at various stages of their life cycle and the definition of priority measures according to the identified most impacting life cycle stages. This situation requires the collection of many life cycle data, too.

Therefore, companies would benefit from the use of simplified analysis before starting a full LCA application. Though the usefulness of fossil CED has previously been tested in other sectors (Huijbreghts et al. 2006), there is no evidence in literature that its use can effectively support a preliminary LCA in the beverage packaging sector.

This research intends to fulfil this gap by discussing to what extent companies in the beverage packaging sector can benefit from the use of the inventory indicator non-renewable fossil CED for screening life cycle analysis.

The objectives of this paper are to assess if the use of non-renewable fossil CED can be a suitable proxy indicator both (1) to decide which is the packaging alternative with the lowest environmental impact and (2) to identify the most impacting process units of the two products under study, by the means of a comparison with a selection of other impact categories (climate change, fossil depletion, particulate matter formation, photochemical oxidant formation and

terrestrial acidification). Finally, some insights for the selection of the most relevant categories in the context of screening LCAs in the packaging sector are provided.

Starting from these preliminary remarks, this paper considers a single case study in the beverage packaging sector with regard to an Italian company, where LCA methodology was used to: (1) compare two different packaging alternatives and (2) identify the environmental hot spots in the packaging value chain of the two products.

2 Method

With regard to the first objective, the goal of the comparative LCA was to evaluate and compare the potential environmental impacts from cradle to grave of two packaging alternatives used for containing long-life milk (UHT), a laminated carton container consisting of six alternating layers of polyethylene, paper, and aluminium and a triple-layer HDPE bottle. The LCA was made according to ISO 14040 standards. The functional unit chosen was the capacity of the packaging to contain a litre of milk. The process units to be included within the system boundaries were selected to compare the two types of packaging, according to the process units usually considered in the packaging field: raw and auxiliary material extraction and processing, production, transport, use and end-of-life (Mourad et al. 2008; Humbert et al. 2009). Figures 1 and 2 show the product system and the system boundaries, respectively, of the laminated carton container and the HDPE bottle. As the LCA study is of a comparative nature, the environmental and energy loads of the use phase have been considered comparable for both types of packaging and some stages, marked in Figs. 1 and 2, were not included in the system boundaries (Humbert et al. 2009). The data provided for the LCI phase, for both containers, consist of primary and secondary data collected during previous LCA studies conducted for similar products, i.e. for the end of life scenario, some assumptions were made regarding the percentage of waste to landfill, incineration with energy recovery and recycling, according to Italian statistics (Corepla 2004), and some secondary data referencing databases in SimaPro© software used for LCA application.

The quantification of the environmental impacts is conducted with one of the most recommended LCIA methods in the context of the packaging sector (Consumer Goods Forum 2011): ReCiPe 2008 (Goedkoop et al. 2009) with a selection of impact categories recommended at the endpoint level by the ILCD Handbook (EC-JRC 2011), i.e. particulate matter formation and photochemical oxidant formation. Furthermore, the results of the comparative LCA obtained with the non-renewable fossil CED indicator, which was selected as the most significant issue for the study, are compared with the results of the impact categories which are connected with the use of fossil fuels: fossil depletion, climate change, particulate matter and acidification (GreenBlue 2009). As a consequence of this selection, in addition to the set of relevant impact categories provided by ReCiPe 2008, in the LCIA step, the midpoint LCIA method IPCC 2007 (with the 100-year timeframe used, being the timeframe basis for the Kyoto protocol) (Frischknecht and Jungbluth 2007) was considered. Furthermore, energy from fossil fuels and climate change are recognised as of primary interest in the beverage packaging sector (von Falkenstein et al. 2010).

In order to test the robustness of the comparative LCA results, within the life cycle interpretation step, both an uncertainty analysis of the inventory using Monte Carlo statistical technique (Humbert et al. 2009) and a sensitivity analysis on the end-of-life assumptions (Pasqualino et al. 2011) were performed.

With reference to the second objective, each of the product systems in Figs. 1 and 2 was analysed separately in order to determine which are the environmental hot spots in terms of life cycle stages. Again, the LCIA results for all the above-mentioned impact categories were compared with the results coming from the life cycle inventory flow non-renewable fossil CED. In order to compare the results provided by the different methods, a contribution analysis was performed (Dreyer et al. 2003; Pizzol et al. 2011a, b).

3 Results

In Table 1, the results of the comparative LCA obtained using the selected impact categories by ReCiPe 2008, the climate change category by IPCC and the inventory indicator non-renewable fossil CED are displayed as percentage, in order to determine whether different results are provided by the different life cycle categories. The results given by the non-renewable fossil CED indicator are confirmed by all the impact categories considered: the laminated carton container is the packaging solution for containing long-life milk with the best performances from an environmental point of view. As the contribution of fossil fuels was identified as the most significant issue of the analysis, the value provided by non-renewable fossil CED was considered as reference value. Some differences in relative terms can be outlined: there is a minimum deviation from the reference value for fossil fuels depletion and a maximum deviation for particulate matter formation. According to these results, it seems that non-renewable fossil CED undervalues the LCIA results.

Within the life cycle interpretation step, an uncertainty analysis of the inventory for the comparative LCA was performed using Monte Carlo statistical techniques. Table 2 presents the results of the comparison in terms of mean value and standard deviation. Figure 3 shows the graphical

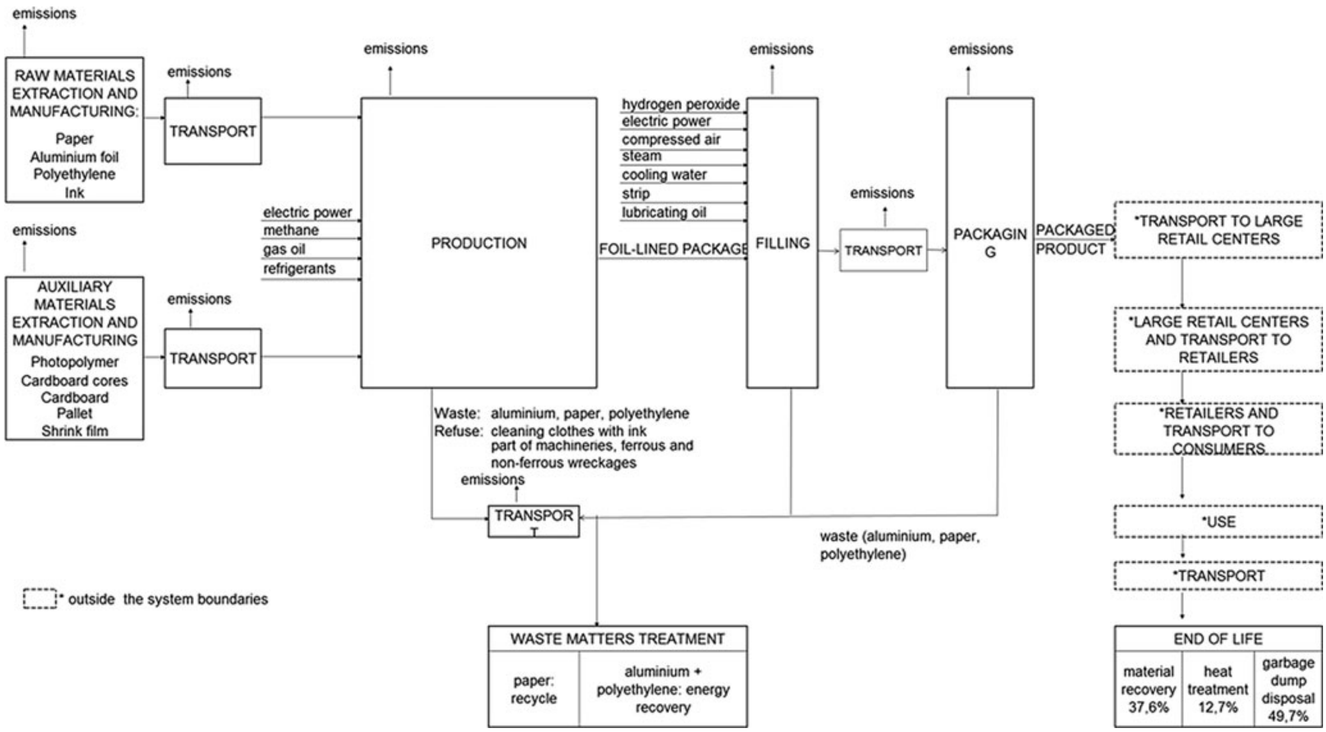

Fig. 1 Product system for the laminated carton container and definition of the processes included in the system boundaries

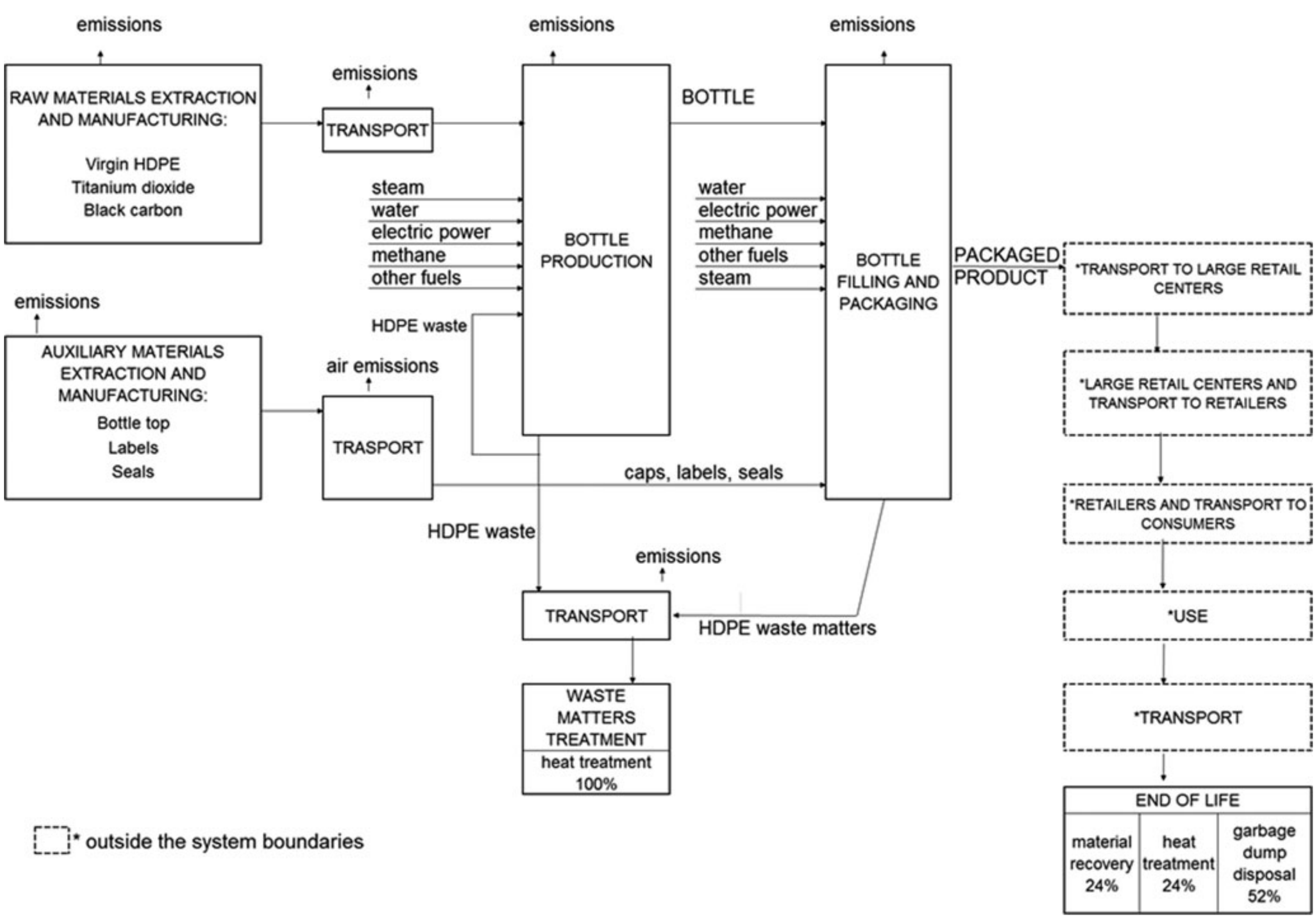

Fig. 2 Product system for the HDPE bottle and definition of the processes included in the system boundaries

Table 1 Inventory and impact categories indicators considered in the comparative LCA between a laminated carton and HDPE bottle for milk

Life cycle category	HDPE bottle (%)	Laminated carton (%)
Non-renewable, fossil CED	100	14.6
Climate change	100	22.8
Fossil fuels depletion	100	14.6
Particulate matter formation	100	31.3
Photochemical oxidant formation	100	23.7
Terrestrial acidification	100	25.3

results of the uncertainty analysis for the comparison between the HDPE bottle and the laminated carton container for the selected categories. It confirms that the impacts of the HDPE bottle are higher than those of the laminated carton container for all impact categories. The level of statistical significance is equal to 100 %. Furthermore, a sensitivity analysis was conducted in order to test the influence of the assumptions on the end-of-life stage to the overall results. Three scenario variants considering different end-of-life parameter were compared, assuming that 100 % of the packaging was disposed through recycling, incineration with energy recovery and landfill, respectively. Table 3 shows, for each selected category, the percentage results between the two packaging alternatives. It confirms that, regardless of the disposal options, the laminated carton container has lower impact than the HDPE bottle. Again, the value provided by non-renewable fossil CED is lower than the results of the other life cycle impact categories.

A further analysis on the LCA results for each single container was conducted with regard to all the selected impact categories in order to define if they are in accordance with the results of the non-renewable fossil CED. Based on the analysis of the laminated carton container, for all impact categories, the largest contributing unit process was raw materials extraction and manufacturing, but in the case of non-renewable fossil CED, as well as all the other impact categories except climate change, the relative contribution is greater than the value emerging from the climate change analysis, as shown in Table 4. Furthermore, the analysis of climate change aspect shows that an important contribution is given by the end-of-life phase, which is, instead, contributing positively to the reduction of the overall impact in the other categories, as it contributes as an avoided impact. A minor difference can be outlined for the impact categories particulate matter formation, terrestrial acidification, photochemical oxidant formation, whose second largest contributing unit is raw materials transport, instead of filling and packaging, which is the second largest contributing unit for non-renewable fossil CED and fossil fuels depletion.

In the case of the HDPE bottle, as shown in Table 5, some differences can be found in the definition of the most impacting process units. They are the production phase for particulate matter formation, terrestrial acidification, photochemical oxidant formation, climate change, and raw material extraction and manufacturing for non-renewable fossil CED and fossil fuels depletion, respectively. Furthermore the contribution from raw material extraction and manufacturing was twice for the energy-related categories. Again, for all categories except climate change, the end-of-life stage had a negative contribution, which is not taken into account by the analysis on the climate change aspect. As a consequence, if one considered only the non-renewable fossil CED, especially in the case of the HDPE bottle, the contribution of the production stage would be underestimated. Furthermore, if one considered only the climate change, for both containers, the analysis of the most contributing process units would be distorted, i.e. the possible positive contribution to the overall impact given by the end-of-life stage would be neglected.

4 Discussion

From the analysis of the results of the comparative LCA and contribution analysis of the packaging under study, some trends can be highlighted if these results are compared with other findings in the beverage packaging literature. From the

Table 2 Results of the uncertainty analysis in terms of mean value and standard deviation for the life cycle of the laminated carton container and the HDPE bottle

Container		Laminated carton container		HDPE bottle	
Life cycle category	Unit of measurement	Mean	Standard deviation	Mean	Standard deviation
Non-renewable fossil CED	MJ	0.735	0.0177	4.99	0.401
Climate change	kg CO_2 eq	0.0609	0.00338	0.262	0.0209
Fossil depletion	$	0.278	0.00763	1.9	0.167
Particulate matter formation	DALY	1.90E−08	4.02E−10	7.8E−08	8.49E−09
Photochemical oxidant formation	DALY	7.99E−12	1.77E−13	2.5E−11	3.57E−12
Terrestrial acidification	species·year	1.48E−12	2.96E−14	5.72E−12	6.26E−13

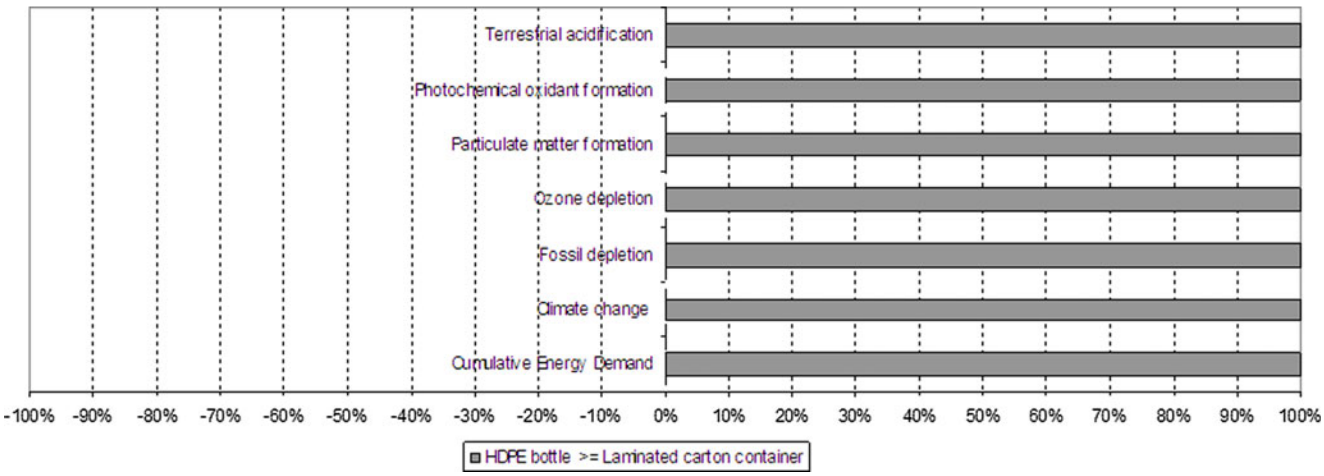

Fig. 3 Graphical results of the uncertainty analysis for the comparison between the HDPE bottle and the laminated carton container for the life cycle categories considered in the comparative LCA

comparative LCA, the use of non-renewable fossil CED revealed to be useful for a screening, as the results are confirmed by other impact categories which have a connection with the non-renewable resources depletion, i.e. climate change, fossil fuels depletion, particulate matter, terrestrial acidification, (GreenBlue 2009) and photochemical oxidant formation. If the aim of the LCA study was to define which is the packaging solution with a lower environmental impact, the choice of an inventory indicator such as non-renewable fossil CED could have led to the same decision as if a comprehensive LCIA method was used.

This result is consistent with the results reported in the meta-analysis conducted by IFEU (von Falkenstein et al. 2009) which provided an overview of LCA applications on beverage cartons (mainly laminated carton container) and other packaging systems. In the case of fresh milk, indeed, the results provided by non-renewable fossil CED are confirmed by other impact categories such as acidification, climate change and summer smog (which corresponds to photochemical oxidant formation). As a consequence, in the milk packaging sector, a screening LCA using non-renewable fossil CED as proxy could be useful in the decision making process. If the performance of the packaging of a company is better than the performance of the competing products, this company can decide to go on with a full LCA.

With regard to the hot spot analysis, as for both containers, the main energy-impacting stage of the life cycle is raw material extraction and manufacturing, the choice of the relevant LCIA category favour a category that is able to quantify the impact of the raw material production processes, which are energy intensive. But the raw material extraction is not the only one relevant life cycle stage in the packaging sector. Our analysis, indeed, revealed that there are other important impacting process, besides raw material extraction and manufacturing, i.e. the end of life stage in relation to climate change or production for the HDPE bottle in relation to particulate matter formation, terrestrial acidification, photochemical oxidant formation. This result is confirmed by other studies involving laminated carton container, i.e. in the milk packaging (Xie et al. 2011) where raw material extraction was the highest of the total environmental impacts contributor in the packaging life cycle except for the disposal stage, as well as in the juice and water packaging (Pasqualino et al. 2011). Considering the results of the

Table 3 Inventory and impact categories indicators considered in the sensitivity analysis focusing on the end of life assumption

End of life option	Recycling		Incineration with energy recovery		Landfill	
Life cycle category	Laminated carton (%)	HDPE bottle (%)	Laminated carton (%)	HDPE bottle (%)	Laminated carton (%)	HDPE bottle (%)
Non-renewable, fossil CED	18.6	100.0	14.5	100.0	14.5	100.0
Climate change	19.2	100.0	16.1	100.0	22.8	100.0
Fossil fuels depletion	18.5	100.0	14.5	100.0	14.5	100.0
Particulate matter formation	90.9	100.0	27.0	100.0	27.4	100.0
Photochemical oxidant formation	24.7	100.0	23.8	100.0	23.8	100.0
Terrestrial acidification	25.5	100.0	25.9	100.0	25.9	100.0

Table 4 Results of the contribution analysis of the laminated carton container

Container	Laminated carton					
Life cycle category Unit process	Non-renewable, fossil CED (%)	Climate change (%)	Fossil depletion (%)	Particulate matter formation (%)	Photochemical oxidant formation (%)	Terrestrial acidification (%)
Raw materials extraction and manufacturing	81.1	55.9	81	74.9	76.3	79.1
Auxiliary materials extraction and manufacturing	1.8	1.1	1.8	2.2	2.1	2
Raw materials transport	5.4	5.1	5.4	9.9	11.5	8
Auxiliary materials transport	0	0	0	0.1	0.1	0
Production	7.8	6.6	7.9	5.9	4.8	5.8
Filling and packaging	9.6	7.4	9.6	8.2	7.5	7.4
Waste matters transport	0.1	0.1	0.1	0.2	0.4	0.2
Waste matters treatment	0	2.1	0	0.1	0.1	0.1
End-of-life	−5.9	21.6	−5.9	−1.3	−2.9	−2.6
Total impact	100	100	100	100	100	100

sensibility analysis, if we assumed that 100 % of the packaging was disposed through recycling, also the results of the hot spot by climate change would confirm the results provided by the other impact categories differently from the base scenario. But the contribution of the recycling stage (representing the end of life stage) is underestimated by climate change, if compared with the contribution analysis provided by the non-renewable fossil CED, as shown in Tables 6 and 7.

This result is consistent with those reported in the paper of Pasqualino et al. (2011), which compares the different stages of the beverages' life cycles considering recycling as a disposal option (aseptic carton for juice, aluminium can for beer and PET bottle for water). From the environmental profile for the different stages of three beverages' life cycle, subtracting the contribution of the beverage to the overall impact, the contribution of the recycling stage (representing the end of life option) is underestimated by climate change, if compared with the contribution analysis provided by non-renewable fossil CED.

Even if there is a correlation between climate change and non-renewable fossil CED, as most of the impact on climate change is attributable to energy consumption, the hot spot analysis provided contrasting results. If the aim of the LCA is to have a rough reliable description of the most impacting process units of the beverage packaging, the suggestion is therefore to consider not only non-renewable fossil CED as indicator but climate change as well.

Table 5 Results of the contribution analysis of the HDPE bottle

Container	HDPE bottle					
Life cycle category Unit process	Non-renewable, fossil CED (%)	Climate change (%)	Fossil depletion (%)	Particulate matter formation (%)	Photochemical oxidant formation (%)	Terrestrial acidification (%)
Raw materials extraction and manufacturing	44.8	23.1	44.8	23.1	19.7	19.6
Auxiliary materials extraction and manufacturing	10	6.7	9.9	13.6	31.2	13
Raw materials transport	0.6	0.9	0.6	1.9	3.1	1.6
Auxiliary materials transport	0.3	0.4	0.3	1	2.1	0.7
Production	34.1	44.8	34.1	45.6	46.6	48.1
Filling and packaging	17.0	15.1	17.1	16.2	17.3	17.3
Waste matters transport	0	0	0	0	0	0
Waste matters treatment	0	1.4	0	0	0.1	0
End-of-life	−6.8	7.7	−6.8	−1.5	−20.2	−0.5
Total impact	100	100	100	100	100	100

Table 6 Results of the contribution analysis of the laminated carton container—sensitivity analysis (end of life 100 % recycling)

Container	Laminated carton					
Life cycle category / Unit process	Non-renewable, fossil CED (%)	Climate change (%)	Fossil depletion (%)	Particulate matter formation (%)	Photochemical oxidant formation (%)	Terrestrial acidification (%)
Raw materials extraction and manufacturing	81.8	74.8	81.8	76.9	80.8	80.6
Auxiliary materials extraction and manufacturing	1.8	1.5	1.8	2.2	2.3	2.0
Raw materials transport	5.5	6.8	5.5	10.2	12.2	8.2
Auxiliary materials transport	0	0	0	0.1	0.1	0
Production	7.9	8.9	7.9	6.0	5.1	5.9
Filling and packaging	9.7	9.9	9.7	8.4	7.9	7.5
Waste matters transport	0.1	0.1	0.1	0.2	0.4	0.2
Waste matters treatment	0	2.8	0	0.1	0.1	0.1
End-of-life	−6.9	−4.8	−6.9	−4.0	−8.9	−4.5
Total impact	100	100	100	100	100	100

5 Conclusions

LCA methodology is time consuming and requires many efforts for data collection. What could be useful for a company in the packaging field is the conduction of a preliminary screening analysis which needs less data to be collected.

The present study focused on the significance of the use of non-renewable fossil CED as proxy indicator in the beverage packaging sector, in order to detect those situations in which companies can benefit from the use of proxy indicators before starting a full LCA application. The aim was to test if the results provided by the LCI indicator non-renewable fossil CED are consistent with those of a full LCA using a comprehensive LCIA method such as ReCiPe for a selection of impact categories and a midpoint method such as IPCC 2007 for climate change with regard to two typical situation within LCA, namely product comparison and product improvement.

A case study within an Italian company in the beverage packaging sector was considered, where LCA methodology was used to: (1) compare two different packaging alternatives and (2) identify the environmental hot spots in the packaging value chain of the two products.

In the first application, a comparative LCA study was applied to two containers for milk, a laminated carton container and an HDPE bottle, and the results of each study were compared. Three different types of life cycle categories were selected, an inventory indicator (non-renewable fossil

Table 7 Results of the contribution analysis of the HDPE bottle—sensitivity analysis (end of life 100 % recycling)

Container	HDPE bottle					
Life cycle category / Unit process	Non-renewable, fossil CED (%)	Climate change (%)	Fossil depletion (%)	Particulate matter formation (%)	Photochemical oxidant formation (%)	Terrestrial acidification (%)
Raw materials extraction and manufacturing	44.9	25.2	44.8	23.2	19.9	19.7
Auxiliary materials extraction and manufacturing	10	7.3	10	13.7	31.5	13
Raw materials transport	0.6	1	0.6	1.9	3.1	1.6
Auxiliary materials transport	0.3	0.4	0.3	1	2.1	0.7
Production	34.1	48.9	34.2	45.8	47.1	48.2
Filling and packaging	17.1	16.5	17.1	16.3	17.4	17.4
Waste matters transport	0	0	0	0	0	0
Waste matters treatment	0	1.6	0	0	0.1	0
End-of-life	−6.9	−1.0	−6.9	−2.0	−21.2	−0.8
Total impact	100	100	100	100	100	100

CED), the midpoint LCIA method IPCC 2007 (climate change) and a selection of energy-related impact categories from one comprehensive LCIA methodology (ReCiPe 2008): photochemical oxidant formation, particulate matter formation, terrestrial acidification and fossil depletion. Regardless of the impact method chosen and considering the outcomes of both uncertainty and sensibility analysis, the less impacting packaging is the laminated carton container. This application confirms the predictability of an LCIA result out of a proxy indicator in the milk packaging sector, where energy data are the most available.

The second application, focusing on the identification of environmental hot spots in the packaging value chain, revealed that the choice of an inventory indicator as non-renewable fossil CED can lead to contrasting results, if compared with another impact category. Indeed, there could be other unit processes responsible for the environmental impact, not necessarily the raw materials and extraction process being the most impacting, as demonstrated by the analysis at climate change level, which gives more relevance to the end of life stage.

Ultimately, this study leads to two conclusions: in the beverage packaging sector, the use of the screening LCI indicator non-renewable fossil CED: (1) can be useful to determine which is the alternative with the lowest environmental impact, but (2) can lead to misleading decisions when assessing the contribution of life cycle stages to the overall impact. Therefore companies in the beverage packaging sector can benefit for the use of non-renewable fossil CED if their aim is to obtain a preliminary estimation of the life cycle environmental impacts of two or more competing products.

Finally, some insights can be formulated to decide which impact categories need to be considered within a screening analysis in the beverage packaging sector. The importance of raw material extraction and manufacturing stages to the overall impact and the importance of fossil fuel contributions to the total resource extraction cannot be neglected. At the same time, the importance of the end of life stage cannot be ignored because the environmental impacts in the beverage packaging sector could not be fully explained by fossil energy use. As a consequence, non-renewable fossil CED and climate change can be used together to provide a rough estimation of the environmental profile in the beverage packaging sector. It could be interesting to test if this correlation is valid also within other sectors, apart from milk packaging.

As in the future development of beverage packaging system LCA will be necessarily integrated in the design process, it is important to define some ways of simplifying its application and spread its use among companies. However, companies need to be aware that the results of a screening LCA should not be used for comparative assertions to be disclosed to the public. Additional research is required to define which unit process could be safely omitted while analysing or comparing different beverage packaging alternatives without greatly affecting the results. Further investigation is also needed in order to define specific guidelines that can help in the selection of the most suitable LCIA categories for screening LCAs according not only to the objective and purpose of the study, but also to the industrial sector.

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References

Bovea MD, Gallardo A (2006) The influence of impact assessment methods on materials selection for eco-design. Mater Design 27:209–215

Brendt ER (1982) From technology to net energy analysis: engineers, economists and recurring energy theories of value. Massachusetts Institute of Technology, Studies in Energy and the American Economy, Discussion Paper No. 11, MIT-EL 81-065WP, September 1982

Consumer Goods Forum (2011) Global Protocol on Packaging Sustainability 2.0, Unpublished document. http://globalpackaging.mycgforum.com/allfiles/GPPS_2.pdf. Accessed 20 January 2012

Corepla (2004) Programma specifico di prevenzione 2004. Arti grafiche quadrifoglio, Milano

Dreyer LC, Niemann AL, Hauschild MZ (2003) Comparison of three different LCIA methods: EDIP97, CML2001 and Eco-indicator 99: does it matter which you choose. Int J Life Cycle Assess 8:191–200

EC-JRC (2011) International Reference Life Cycle Data System (ILCD) Handbook—recommendations for life cycle impact assessment in the European context. First edition November 2011. European Commission-Joint Research Centre—Institute for Environment and Sustainability: EUR 24571 EN. Luxemburg. Publications Office of the European Union

Frischknecht R, Jungbluth N (2007) Implementation of life cycle assessment methods. Ecoinvent report No. 3, Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland

Goedkoop M, Heijungs R, Huijbreghts, De Schryver A, Struijs J, van Zelm R (2009) ReCiPe 2008. A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. First edition. Report I: Characterisation. 6 January 2009. Full report available at http://www.lcia-recipe.net/

GreenBlue (2009) Sustainable Packaging Indicators and Metrics Framework, Version 1.0, unpublished report, Charlottesville, VA, US. www.greenblue.org. Accessed 20 January 2012

Hannon BM (1972) System energy and recycling: a study of the container industry. American Society of Mechanical Engineers, New York, 72-WA-ENER-3

Hannon BM (1980) The energy cost of energy. Energy Research Group, University of Illinois at Urbana—Champagne, xerolith, (revised), June 1980

Hannon BM (2010) The role of input–output analysis and ecological systems: in the early development of ecological economics—personal perspective. Ann NY Acad Sci 1185:30–38

Hauschild MZ, Huijbregts M, Jolliet O, Macleod M, Margni M, Vab De Meent D, Rosenbraum R, McKone T (2008) Building a model based on scientific consensus for life cycle impact assessment of chemicals: the search for harmony and parsimony. Environ Sci Technol 42:7032–7037

Huijbreghts MAJ, Rombouts LJ, Hellweg S, Frischknecht R, Hendriks AJ, van de Meent D, Ragas AMJ, Reijnders L, Struijs J (2006) Is cumulative fossil energy demand a useful indicator for the environmental performance of products? Environ Sci Technol 40 (3):641–648

Humbert S, Rossi V, Margni M, Jolliet O, Lerincik Y (2009) Life cycle assessment of two baby food packaging alternatives: glass jars vs. plastic pots. Int J Life Cycle Assess 14:95–106

Hunt RG, William EF (1996) LCA—how it came about—personal reflections on the origin and the development of LCA in the USA. Int J Life Cycle Assess 1(1):4–7

Manzardo A, Mazzi A, Levorato B, Niero M, Scipioni A (2011) Single issue assessment VS full life cycle assessment: the case of a monocrystalline PV panel. In: Proceedings of LCM 2011 “Towards Life Cycle Sustainability Management”, 28–31 August 2011, Berlin, Germany

Mizsey P, Delgado L, Benko T (2009) Comparison of environmental impact and external cost assessment methods. Int J Life Cycle Assess 14:665–675

Mourad AL, Garcia EEC, Braz Vilela G, Von Zuben F (2008) Environmental effects from a recycling rate increase of cardboard of aseptic packaging system for milk using life cycle approach. Int J Life Cycle Assess 13:140–146

Pant R, Van Hoof G, Schowanek D, Feijtel TCJ, de Koning A, Hauschild M, Penningron DW, Olsen SI, Rosenbaum R (2004) Comparison between three different LCIA methods for aquatic ecotoxicity and a product environmental risk assessment. Int J Life Cycle Assess 9:295–306

Pasqualino J, Menes M, Castells F (2011) The carbon footprint and energy consumption of beverage packaging selection and disposal. J Food Eng 103:357–365

Pizzol M, Christensen P, Schmidt J, Thomsen M (2011a) Impacts of “metals” on human health: a comparison between nine different methodologies for life cycle impact assessment (LCIA). J Clean Prod 19:646–656

Pizzol M, Christensen P, Schmidt J, Thomsen M (2011b) Ecotoxicological impact of “metals” on the acquatic and terrestrial ecosystem: a comparison between eight different methodologies for life cycle impact assessment (LCIA). J Clean Prod 19:687–698

Von Falkenstein E, Detzel A, Wellenreuther F (2009) Meta analysis: LCA studies on beverage cartons and alternative packaging. Final report. IFEU—Institute fur Energie und Umweltforschung Heidelberg GmbH

Von Falkenstein E, Wellenreuther F, Detzel A (2010) LCA studies comparing beverage cartons and alternative packaging: can overall conclusions be drawn? Int J Life Cycle Assess 15:938–945

Xie M, Li L, Qiao Q, Sun Q, Sun T (2011) A comparative study on milk packaging using life cycle assessment: from PA-PE-Al laminate and polyethylene in China. J Clean Prod 19:2100–2106